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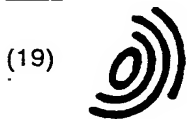
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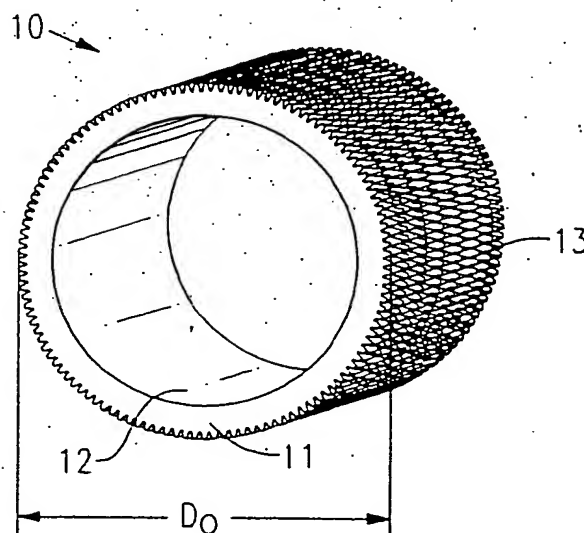
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## (54) Heat transfer tube

(57) A heat transfer tube (10) for use in a heat exchanger where heat is transferred between a fluid flowing through the tube and a fluid flowing around the exterior of the tube and where the fluid external to the tube boils during the heat exchange process. The tube has at least one fin convolution (20) extending helically around its external surface (13). A pattern of notches (30) extends at an oblique angle ( $\alpha$ ) across the fin convolution at intervals about the circumference of the tube. There is a spike (22) between each pair of adjacent notches. The distal tip (23) is flattened. The maximum width ( $W_t$ ) of the spike is greater than the width ( $W_n$ ) of the proximal portion of the fin convolution and is of a

width sufficient to overlap with the distal tips of spikes in adjacent fin convolutions, thus forming reentrant cavities between the adjacent fin convolutions and under the overlapping tips. The fin convolution, notches and spikes are formed in the tube by rolling the wall of the tube between a mandrel and, first, a gang of finning disks (63), then second, a notching wheel (66) and, third, a smooth wheel (67). Because, during the manufacture of the tube, of the interaction of the rotating and advancing tube, the notching wheel and the smooth wheel, the angle ( $\beta$ ) of inclination of the axis of the tip of the spike is oblique with respect to the notch angle

FIG.1



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## Description

## BACKGROUND OF THE INVENTION

5 The present invention relates generally to heat transfer tubes. In particular, the invention relates to the external surface configuration of a heat exchanger tube that is used for evaporation of a liquid in which the tube is submerged.

Many types of air conditioning and refrigeration systems contain shell and tube type evaporators. A shell and tube evaporator is a heat exchanger in which a plurality of tubes are contained within a single shell. The tubes are customarily arranged to provide a multiplicity of parallel flow paths through the heat exchanger for a fluid to be cooled. The tube  
10 are immersed in a refrigerant that flows through the heat exchanger shell. The fluid is cooled by heat transfer through the walls of the tubes. The transferred heat vaporizes the refrigerant in contact with the exterior surface of the tubes. The heat transfer capability of such an evaporator is largely determined by the heat transfer characteristics of the individual tubes. The external configuration of an individual tube is important in establishing its overall heat transfer characteristics.

15 There are several generally known methods of improving the heat transfer performance of a heat transfer tube. Among these are (1) increasing the heat transfer area of the tube surface and (2) promoting nucleate boiling on the surface of the tube that is in contact with the boiling fluid. In the nucleate boiling process, heat transferred from the heated surface vaporizes liquid in contact with the surface and the vapor forms into bubbles. Heat from the surface superheats the vapor in a bubble and the bubble grows in size. When the bubble size is sufficient, surface tension is  
20 overcome and the bubble breaks free of the surface. As the bubble leaves the surface, liquid enters the volume vacated by the bubble and vapor remaining in the volume has a source of additional liquid to vaporize to form another bubble. The continual forming of bubbles at the surface, the release of the bubbles from the surface and the rewetting of the surface together with the convective effect of the vapor bubbles rising through and mixing the liquid result in an improved heat transfer rate for the heat transfer surface.

25 It is also well known that the nucleate boiling process can be enhanced by configuring the heat transfer surface so that it has nucleation sites that provide locations for the entrapment of vapor and promote the formation of vapor bubbles. Simply roughening a heat transfer surface, for example, will provide nucleation sites that can improve the heat transfer characteristics of the surface over a similar smooth surface. In boiling liquid refrigerants, for example in the evaporator of an air conditioning or refrigeration system, nucleation  
30 sites of the re-entrant type produce stable bubble columns and good surface heat transfer characteristics. A re-entrant type nucleation site is a surface cavity in which the opening of the cavity is smaller than the subsurface volume of the cavity. An excessive influx of the surrounding liquid can flood a re-entrant type nucleation site and deactivate it. By configuring the heat transfer surface so that it has relatively larger communicating subsurface channels with relatively smaller openings to the surface, flooding of the vapor entrapment or nucleation sites can be reduced or prevented and  
35 the heat transfer performance of the surface improved.

## SUMMARY OF THE INVENTION

40 The present invention is a heat transfer tube having one or more fin convolutions formed on its external surface. Notches extend at an oblique angle across the fin convolutions at intervals about the circumference of the tube. There is a fin spike between each adjacent pair of notches in a fin convolution. The distal tip of the a fin spike is flattened and wider than the fin root. The width of the tip is such that there is overlap between the tips of fin spikes in adjacent fin convolutions thus forming reentrant cavities between the fin convolutions.

45 The notches in the fin further increase the outer surface area of the tube as compared to a conventional finned tube. In addition, the configuration of the flattened fin spikes and the cavities formed by them promote nucleate boiling on the outer surface of the tube.

Manufacture of a notched fin tube can be easily and economically accomplished by adding an additional notching disk to the tool gang of a finning machine of the type that forms fins on the outer surface of a tube by rolling the tube wall between an internal mandrel and external finning disks.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings form a part of the specification. Throughout the drawings, like reference numbers identify like elements.

55 FIG. 1 is a pictorial view of the tube of the present invention.

FIG. 2 is a view illustrating how the tube of the present invention is manufactured.

FIG. 3 is a plan view of a portion of the external surface of the tube of the present invention.

FIG. 4 is a plan view of a portion a single fin convolution of the tube of the present invention.

a) there are 13 to 28 fin convolutions per centimeter (33 to 62 fin convolutions per inch) of tube length, i.e. the fin pitch is 0.036 to 0.84 millimeter (0.014 to 0.033 inch), or

$$0.036 \text{ mm} \leq P_f \leq 0.84 \text{ mm} \quad (0.014 \text{ inch} \leq P_f \leq 0.033 \text{ inch});$$

b) the ratio of fin height to tube outer diameter is between 0.02 and 0.05, or

$$0.02 \leq H_f / D_o \leq 0.05;$$

c) the density of notches in the fin convolution is 17 to 32 notches per centimeter (42 to 81 notches per inch);

d) the angle between the notch axis and the tube longitudinal axis is between 40 and 70 degrees, or

$$40^\circ \leq \alpha \leq 70^\circ \text{ and}$$

e) the notch depth is between 0.2 and 0.8 of the fin height or

$$0.2 \leq D_n / H_f \leq 0.8.$$

The optimum number of fin convolutions, or fin "starts" depends more on considerations of ease of manufacture rather than the effect of the number on heat transfer performance. A higher number of starts increases the rate at which the fin convolutions can be formed on the tube surface but increases the stress on the finning tools.

### Claims

1. An improved heat transfer tube (10) in which the improvement comprises:

at least one external fin convolution (20) disposed helically about of said tube;  
notches (30) extending radially into said fin convolution at intervals about the circumference of said tube;  
each of said notches having a base axis that is at an oblique angle ( $\alpha$ ) with respect to the longitudinal axis ( $A_T$ ) of said tube;  
said notches dividing said fin convolution into a proximal portion (21) and a spike portion (22) having a single flattened distal tip (23),  
said spike portion being between a pair of adjacent said notches and having a maximum width ( $W_t$ ) that is both greater than the maximum width ( $W_p$ ) of said proximal portion and sufficient so that said spike overlaps with spikes in both adjacent fin convolutions and  
a distal tip axis ( $\beta$ ) that is oblique to said notch base axis.

2. The tube of claim 1 in which:

there are 13 to 28 fin convolutions per centimeter (33 to 70 fin convolutions per inch) of tube;  
the ratio ( $H_f / D_o$ ) of the height of said fin convolution ( $H_f$ ) to the outer diameter of said tube ( $D_o$ ) is between 0.02 and 0.05;  
the density of said notches in said fin convolution is 17 to 32 notches per centimeter (42 to 81 notches per inch);  
the angle between said notch base axis and said tube longitudinal axis is between 40 and 70 degrees; and  
the depth of said notches is between 0.2 and 0.8 of said fin convolution height.

3. A heat transfer tube (10) comprising:

a tube wall (11) having an outer surface (13);  
at least one fin convolution (20) formed by the interaction of a finning disk (63) and a mandrel (64), extending from said tube outer surface;  
notches (30), formed by a notching wheel (66), extending radially into said fin convolution at intervals about the circumference of said tube, and dividing said fin convolution into a proximal portion and a spike portion (22),  
each of said notches having a base axis that is at an oblique angle ( $\alpha$ ) with respect to the longitudinal axis ( $A_T$ ) of said tube; and  
said spike portion (22) having a flattened distal tip (23), formed by said notching wheel and a smooth wheel (67), between a pair of adjacent said notches, that overlaps with similar distal tips in both adjacent fin convolutions,  
said distal tip being between a pair of adjacent said notches and having a maximum width ( $W_t$ ) that is greater than the maximum width ( $W_p$ ) of said proximal portion and a distal tip axis ( $\beta$ ) that is oblique to said notch base axis.

FIG. 5 is a generic sectioned elevation view of a single fin convolution of the tube of the present invention.

FIGS. 5A, 5B, 5C and 5D are sectioned elevation views, through, respectively, lines 5A-5A, 5B-5B, 5C-5C and 5D-5D in FIG. 4, of a single fin convolution of the tube of the present invention.

## 5 DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is a pictorial view of heat transfer tube 10. Tube 10 comprises tube wall 11, tube inner surface 12 and tube outer surface 13. Extending from the outer surface of tube wall 11 are external fins 22. Tube 10 has outer diameter  $D_o$ , including the height of fins 22.

10 The tube of the present invention may be readily manufactured by a rolling process. FIG. 2 illustrates such a process. In FIG. 2, finning machine 60 is operating on tube 10, made of a malleable metal such as copper, to produce both interior ribs and exterior fins on the tube. Finning machine 60 has one or more tool arbors 61, each containing tool gang 62, comprised of a number of finning disks 63, notching wheel 66 and smooth wheel 67. Extending in to the tube is mandrel shaft 65 to which is attached mandrel 64.

15 Wall 11 is pressed between mandrel 64 and finning disks 63 as tube 10 rotates. Under pressure, metal flows into the grooves between the finning disks and forms a ridge or fin on the exterior surface of the tube. As it rotates, tube 10 advances between mandrel 64 and tool gang 62 (from left to right in FIG. 2) resulting in a number of helical fin convolutions being formed on the tube, the number being a function of the number of tool arbors 61 in use on finning machine 60. In the same pass and after tool gang 62 forms fins on tube 10, notching wheel 66 impresses oblique notches into the fins then smooth wheel 67 flattens and spreads the distal tips of the fins.

20 Mandrel 64 may be configured in such a way, as shown in FIG. 2, that it will impress some type of pattern into the internal surface of the wall of the tube passing over it. A typical pattern is of one or more helical rib convolutions. Such a pattern can improve the efficiency of the heat transfer between the fluid flowing through the tube and the tube wall.

FIG. 3 shows, in plan view, a portion of the external surface of the tube. Extending from outer surface 13 of tube 25 10 are a number of fin convolutions 20. Extending obliquely across each fin convolution at intervals are a pattern of notches 30. Between each pair of adjacent notches in a given fin convolution is a fin spike (22) having a distal tip 23. The fin pitch, or distance between adjacent fin convolutions, is  $P_f$ .

FIG. 4 is a plan view of a portion of a single fin convolution of the tube of the present invention. The angle of inclination of notch base 31 from longitudinal axis of the tube  $A_T$  is angle  $\alpha$ . The angle of inclination of fin distal tip 23 30 from longitudinal axis of the tube  $A_T$  is angle  $\beta$ . Because, during manufacture of the tube (see FIG. 2), of the interaction between rotating and advancing tube 10, notching wheel 66 and smooth wheel 67, the axis of spike 22 is turned slightly from the angle between the teeth of the notching wheel and the fin convolution so that tip axis angle  $\beta$  is oblique with respect to angle  $\alpha$ , i.e.,  $\beta \neq \alpha$ .

FIG. 5 is a pseudo sectioned elevation view of a single fin convolution of the tube of the present invention. We use 35 the term pseudo because it is unlikely that a section taken through any part of the fin convolution would look exactly as the section depicted in FIG. 5. The figure, however, serves to illustrate many of the features of the tube. Fin convolution 20 extends outward from tube wall 11. Fin convolution 20 has proximal portion 21 and spike 22. Extending through the fin at the pseudo section illustrated is a notch having notch base 32. The overall height of fin convolution 20 is  $H_f$ . The width of proximal portion 21 is  $W_p$  and the width of spike 22 at its widest dimension is  $W_s$ . The outer 40 extremity of spike 22 is distal tip 23. The distance that the notch penetrates into the fin convolution or notch depth is  $D_n$ . Notching wheel 66 (FIG. 2) does not cut notches out of the fin convolutions during the manufacturing process but rather impresses notches into the fin convolutions. The excess material from the notched portion of the fin convolution moves both into the region between adjacent notches and outwardly from the sides of the fin convolution as well as toward tube wall 11 on the sides of the fin convolution. As a result,  $W_s$  is significantly greater than  $W_p$  and is sufficient 45 so that the distal tips of spikes in adjacent fin convolutions overlap one another so that reentrant cavities are formed between adjacent fin convolutions and under the overlapping distal tips.

FIGS. 5A, 5B, 5C and 5D are sectioned elevation views of fin convolution 20 respectively taken at lines 5A-5A, 5B-5B, 5C-5C and 5D-5D in FIG. 4. The views show more accurately the configuration of notched fin convolution 20 50 at various points as compared to the pseudo view of FIG. 5. The features of the notched fin convolution discussed above in connection with FIG. 5 apply equally to the illustrations in FIGS. 5A, 5B, 5C and 5D.

We have tested a prototype tube made according to the teaching of the present invention. That tube has a nominal outer diameter ( $D_o$ ) of 1.9 centimeters (3/4 inch), a fin height of 0.61 millimeters (0.0241 inches), a fin density of 22 fin convolutions per centimeter (56 fin convolutions per inch) of tube length, 122 notches per circumferential fin convolution, the axis of the notches being at an angle of inclination ( $\alpha$ ) from the tube longitudinal axis ( $A_T$ ) of 45 degrees and a notch depth of 0.20 millimeter (0.008 inch). The tested tube has three fin convolutions, or, as is the term in the art, 55 "three starts."

Extrapolations from test data indicate that the external surface configuration of the tube of the present is suitable for tubes having nominal outer diameters of from 12.5 millimeter (1/2 inch) to 25 millimeter (1 inch) where:

FIG.1

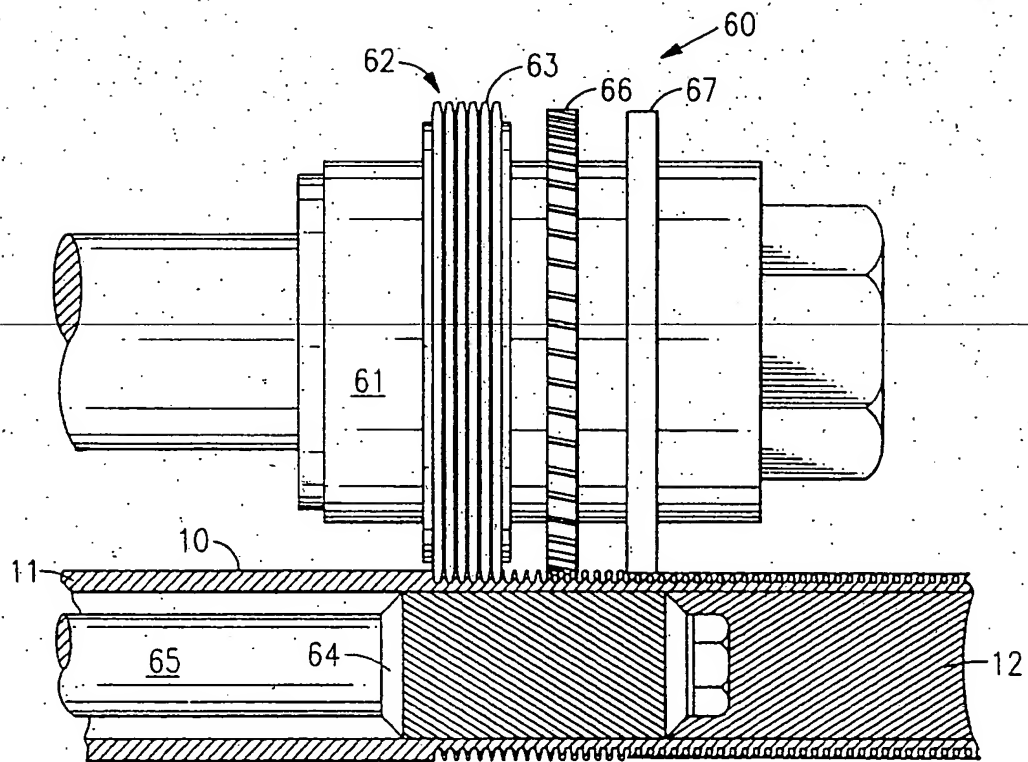
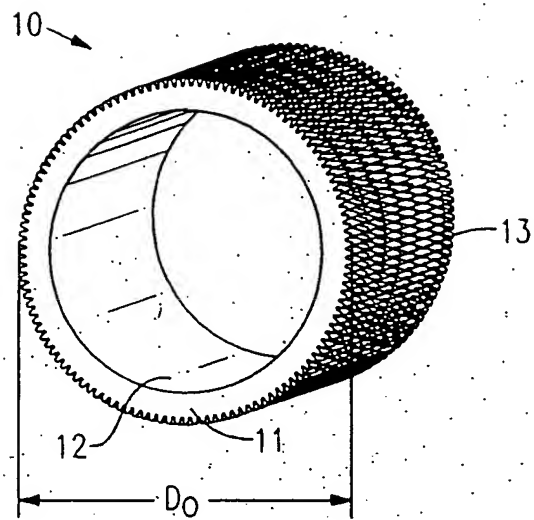


FIG.2

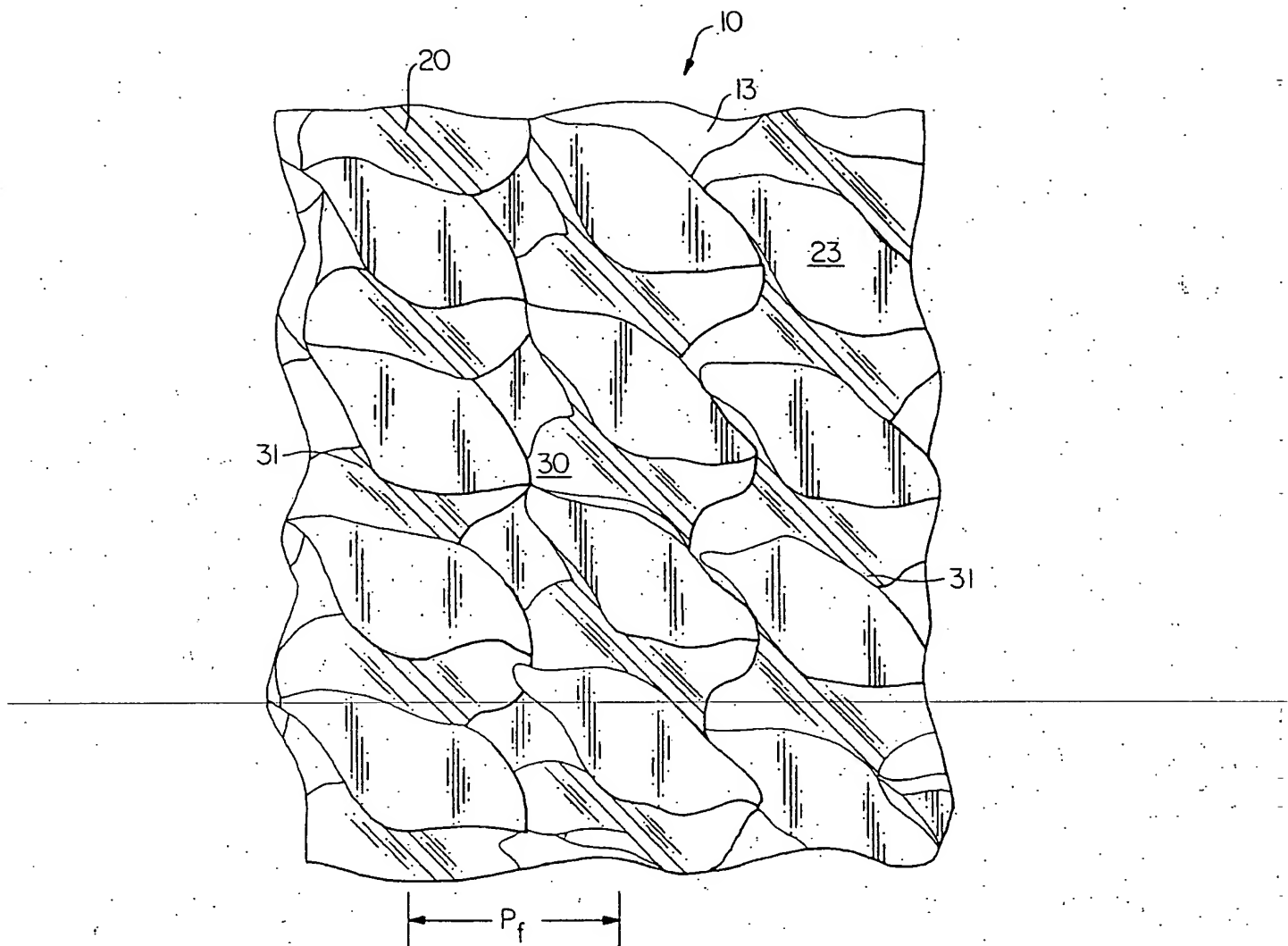


FIG.3

